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Cold Starting a Neat Methanol (M100) Vehicle with Long Duration Spark Ignition

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Technical Report

Cold Starting A Neat Methanol (M100) Vehicle With Long Duration Spark Ignition

by

Robert I. Bruetsch

June 1989

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16. ABSTRACT

A test program was devised at EPA's Motor Vehicle Emission Laboratory to evaluate the Nissan long duration spark ignition (LDSI) system on an M100 test vehicle to determine whether cold starting neat methanol at low ambient temperatures can be improved. Modifications were made to the vehicle's ignition system and stock cold start injectors were utilized. Successful cold starts were obtained down to 20 F.

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I. Summary

A test program was devised at EPA's Motor Vehicle Emission Laboratory to evaluate the Nissan long duration spark ignition (LDSI) system on an M100 test vehicle to determine whether cold starting neat methanol at low ambient temperatures can be improved. Modifications were made to the vehicle's ignition system and stock cold start injectors were utilized. Successful cold starts were obtained down to 20°F (-7°C).

II. Background

Nissan initially developed this system to investigate the relationship between spark-ignition characteristics and combustion stability in a gasoline-fueled engine. They examined spark current, energy, and duration parameters and found that lengthening the spark discharge duration is particularly effective in achieving stabilized combustion.[1]

More specifically, a longer spark duration was found to provide a continued supply of electrical energy to the mixture around the spark plug gap. A longer spark duration promotes more rapid flame initiation and faster flame kernel growth. The length of spark duration is generally regarded as the period from ignition to the onset of combustion pressure rise. Since energy is continually input as the flame kernel grows, the occurrence of misfire cycles should be suppressed in the vicinity of the advance limit for ignition timing and the heat release delay time should be shortened. The result should be a reduction in combustion fluctuations, thereby making it possible to expand the stable combustion zone and fire leaner mixtures. Combustion stability is essential for reduced NOx emissions and improved fuel economy in a lean burn engine. It is also beneficial for good combustion in cold weather and for better response in transient operating conditions. Lengthening spark duration should also expand the stable EGR rate limit.[2]

In 1987, General Motors Research Labs published a paper describing a development program in which they claimed to achieve unassisted cold starts with a UPS direct injection stratified charge (DISC) engine at ambient temperatures as low as -20°F with M100 and other alcohol fuels. The special characteristics optimized for this engine included high compression ratio, a multiple discharge spark system, in cylinder air motion and direct injection.[3]

The Nissan LDSI system is somewhat different in design and operation than the ignition system used in the UPS engine tested by GM, but is similar in its improved spark energy characteristics for cold starting alcohol fuels.[4] Improved cold start performance of M100 was the main objective of this test program, so it was decided to apply the Nissan LDSI to a high compression M100-fueled engine without direct injection, stratified charge, or optimized air motion, to evaluate its component contribution to the improvement of low ambient temperature neat methanol cold start performance.

III. System Description

The Nissan LDSI system consists of a power unit containing spark duration control circuitry and a high voltage output, an ignition relay, and a duration control box which allows spark duration to be varied from 4 to 10 milliseconds. Further lengthening of spark duration is believed by Nissan to cause fuel economy to deteriorate because of the increase in electric power consumption. Spark plugs may also wear out sooner due to electrode erosion.[2] When power to the system is cut off, the test vehicle runs on the stock ignition system with spark duration on the order of 1.5 milliseconds. A schematic of the Nissan LDSI hardware is shown in Appendix A. The control circuit in the LDSI power unit was treated as a "black box" in the evaluation, but is believed by EPA to include a DC-DC converter which enables the spark duration to be varied.[5]

The LDSI power unit has a four-pin connector in addition to the high voltage output. One pin is connected to the battery or other +12V supply. A second pin is connected to ground. A third pin is provided to receive input from the vehicle ignition pulse generator, in this case a magnetic Hall-Effect transistorized crank position sensor system. The fourth pin can be used as an output to a tachometer if required.

An additional pulse interface circuit was developed to mate the Nissan LDSI system to the test vehicle's ignition coil, distributor and pulse generator. The vehicle's ignition pulse was measured and recorded at 850 rpm (idle). A typical printout of the pulse characteristics and the pulse interface circuit are shown in Appendix B. The pulse printout data are displayed in graphic form as plots of voltage (mV) versus time (ms). These plots can be used to determine the pulse width and the pulse frequency of a given engine condition as produced by the vehicle's ignition pulse generator.

The pulse interface circuit was developed for use with the vehicle's ignition timing to regulate the pulse frequency or duty cycle of the LDSI, i.e., no delay circuit or other rpm-dependent circuit was incorporated into the pulse interface circuit.

The Nissan LDSI only accepts a 5-volt square-wave ignition pulse nominally 4 to 5 milliseconds wide. This is based on an ignition coil primary circuit current of approximately 5 amperes and an ignition coil secondary circuit current of approximately 40 to 50 milliamperes.[6] The test vehicle's ignition pulse was detected (located on the distributor) at idle (roughly 850 rpm) and at 1600 rpm using a Norland Digital Oscilloscope and printer. The pulse interface circuit was then designed to transform these pulse characteristics into the required 5V square-wave for the LDSI.

The pulse interface circuit contains three integrated circuits: IC1, IC2, and IC3.[7] IC1 and its associated components (a metal oxide varistor, two diodes, and two capacitors) drop the nominal 12 volts from the battery down to 5 volts to power the rest of the circuit. The metal oxide varistor is a transient suppressor which protects the circuit from damaging voltage spikes. The diodes protect the circuit in case of accidental polarity reversal and the capacitors filter the power supply.

IC2 and its components (two resistors and a capacitor) form a voltage comparator. The two resistors make up a voltage divider which provides IC2, an operational amplifier, with a reference voltage.

$$V_{ref} = \frac{(5)(1000)}{(1000+1800)} = 1.79 \text{ volts}$$

When the input voltage from the distributor pickup (pulse generator) exceeds the reference, the voltage at the output of IC2 switches from 0 volts to 5 volts.

The output of IC2 is connected to a monostable multivibrator (IC3). A pull-down resistor ensures a relatively low resistance path to ground for IC3 when the output of IC2 is at a low level. When there is a low-to-high transition at the "B" input of IC3, there is a positive-going pulse at the "Q" output of IC3. The duration of the pulse is determined by resistors R4 and R5 and capacitor C4:

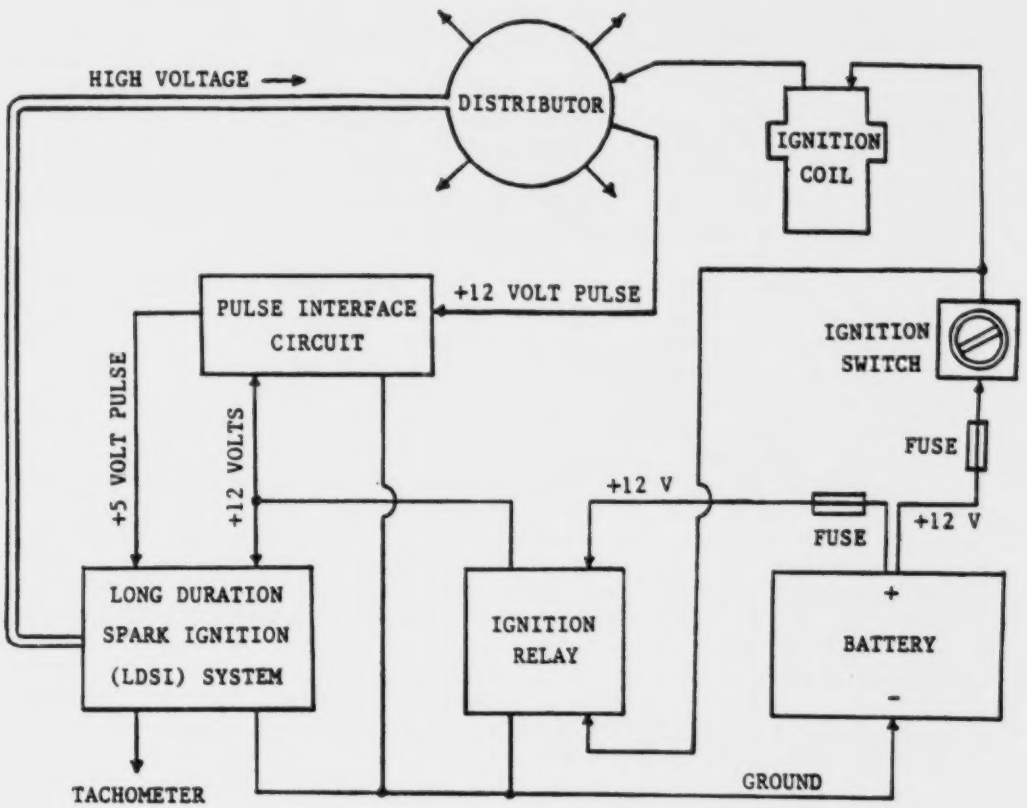
$$t_{pulse} = \ln(2) \times R \times C = 4 \text{ msec}$$

The pulse current is amplified by two transistors before being output to the Nissan LDSI system.

A schematic of the entire vehicle ignition system as modified for this test program is shown in Figure 1. A nominal 12 volts is sourced from the vehicle battery through fuses to the ignition switch and ignition relay. The relay is also connected to the other (coil) side of the ignition switch in order to trigger the LDSI system and pulse interface circuit

Figure 1

Modified Test Vehicle Ignition System Schematic



with 12 volts when the vehicle's ignition key is turned on. The rest of the ignition system operates the same as the stock breakerless ignition system, except that the high voltage input to the distributor is connected to the Nissan LDSI power unit rather than the center post of the vehicle ignition coil. The pulse generator signal is input to the pulse interface circuit and transformed into a 5-volt square-wave 4 msec wide as described above. Then, the pulse is input to the Nissan LDSI. The high voltage output of the Nissan LDSI is then input to the distributor and distributed to the spark plugs using the vehicle's stock specification ignition timing (3°ATDC at 850 rpm, 24° BTDC at 4500 rpm).[8]

The test vehicle used for this program is a 1981 Volkswagen Rabbit modified for use of neat methanol (M100). The engine displacement is 1.61 liters and the compression ratio is 12.5:1. The vehicle was not equipped with a catalyst. The equivalent test weight of the vehicle is 2500 lbs. and the actual dynamometer horsepower is 7.7 HP. A more complete description of the neat methanol test vehicle specifications and modifications made to accommodate methanol fuel are included in Appendix C.

A few aspects of the vehicle fueling system are noteworthy. The vehicle is equipped with two cold start enrichment valves which are temperature controlled and electrically operated. These valves enrich the air/fuel mixture at coolant temperatures below approximately 16°C (60°F). They operate for a maximum of 8 seconds depending on outside ambient temperature. The cold start valves are controlled by the thermo-time switch. The thermo-time switch supplies negative current (ground) to the cold start valves so that they will inject fuel into the intake air distributor when the starter is operated and the engine is cold. If the starter is operated for longer than normal, the thermo-time switch cuts off the cold start valves in order to prevent engine flooding. All tests run in this program were performed at coolant temperatures within the operable range of the thermo-time switch (below 35°C). The vehicle's oxygen sensor works according to specification with an idle mixture (CO content) of 2.0 to 3.0 volume percent.[8,9]

IV. Starting Procedure

The vehicle was initially cranked to start in increments of 10 seconds, with the exception of a 15-second crank on the first attempt at each temperature. If the vehicle did not start, a pause of 15 seconds was taken to allow the starter to cool. This cycle of crank and pause was repeated until 55 seconds of cranking time (5 start attempts) had elapsed.

This procedure was originally developed for the protection of the starter when using a 24-volt battery system.[10] The test vehicle was returned to stock configuration for this test program and used a 12-volt battery. Upon repeated starting attempts it was found that if the vehicle didn't start on the first attempt, the 12-volt battery was significantly discharged such that the vehicle would not start or crank as well on subsequent start attempts.

A new starting procedure was adopted which involved cranking for 30 to 45 seconds with the throttle closed. If the vehicle failed to start, a 15-second pause was taken and a second start attempt was made by cranking for approximately 15 seconds. If no start occurred, the vehicle's battery (625 CCA) was connected to a battery charger for 20 to 30 minutes and the procedure was repeated. If the vehicle started, the driver was instructed to throttle the engine in neutral, if necessary, to keep it going and avoid stalling during pre-test idling.[11]

V. Test Results

Test results showed that increasing spark duration up to 10 milliseconds increases the spark energy to over 280 mJ (compared to 26 mJ at 1.5 ms spark duration), and enabled an M100 vehicle to be cold started at ambient, coolant and oil temperatures as low as 20°F (-7°C). Table 1 shows the results of cold start testing around the temperatures which were identified as representing the limits of the Nissan LDSI M100 cold starting capabilities.

The first test listed was merely a baseline test at room temperature to see if the system was operable without relying on the stock ignition system. This test confirmed that the pulse circuit was designed correctly and that the Nissan LDSI could start the vehicle just as well as the stock ignition system can at 75°F. The "Cranking?" column in Table 1 is a subjective measure developed to compare the cranking speed at low temperatures to those at room temperature. Cranking rpm was not measured for these determinations. A rating of "fast" cranking speed is synonomous with the starter cranking speed at room temperature with the stock ignition system (roughly 300 rpm). All other cranking speed ratings were ranked relative to this. The vehicle was soaked overnight in MVEL's outdoor cold box such that inlet air, coolant, and oil temperatures were all within 1°F of each other, and the entire vehicle was at temperatures below the lower limit of the Controlled Environment Test Cell (CETC), i.e., below 20°F (-7°C). Several starting attempts were made in the cold box prior to putting the vehicle in the CETC for an attempted Federal Test Procedure

Table 1

Results of Cold Start Attempts With Long Duration Spark Ignition On An M100-Fueled VW Rabbit

Air/H_2O/Oil Temperature (°F)	(°C)	Start? (Yes/No)	Cranking? (Fast/Slow)	Comments
75	24	Yes	Fast	Same performance as stock ignition
30	-1	Yes	Fast	Start after 28-second crank; FTP aborted in Bag 2 due to high exhaust temperatures
22	-6	Yes	Fast	Start after 15-second crank; FTP aborted in Bag 2 due to power loss
20	-7	Yes	Moderate	Start after 15-second crank; immediate stall; failure to restart at this temperature
18	-8	No	Slow	Some firing
16	-9	No	Very slow	No firing; starter failure on last attempt

(FTP). The vehicle did not start in the teens, but exhibited some backfire and near-starts indicating that the temperature was probably near (just below) the lower limitations of the LDSI system. A 22°F (-6°C) start was obtained in the cold box after a 15-second cranking period with a 10 ms spark duration.

At this point, it was decided to attempt a 20°F (-7°C) FTP in the CETC. The vehicle started at 20°F (-7°C) after 15 seconds of cranking and almost immediately stalled. Subsequent cranking attempts were unsuccessful as the battery quickly discharged. The battery was recharged and another cold start was attempted at 20°F (-7°C). This attempt failed as did the next three iterations. Finally, with the ambient, coolant, and oil temperatures raised slightly to 22°F (-6°C), the vehicle started after 15 seconds of cranking, idled roughly for about 1 minute, and an FTP test was attempted. Driveability was poor, but the vehicle achieved enough power to match the driver's trace throughout Bag 1, including the acceleration to 57 MPH. Immediately after the start of Bag 2, the vehicle exhibited a power loss and had difficulty running at speeds over 5 MPH, let alone matching the driver's trace. Approximately one-third of the way through Bag 2, the CO alarm in the test cell sounded and the test was aborted. Bag 1 of this test was analyzed and found to be very high in emissions with 469 grams of CO and 406 grams of methanol emissions. Complete test results for this and a subsequent attempt to perform an FTP test are contained in Appendix D. Gasoline equivalent fuel economy was 10.6 MPG for this one-bag test.

Several cold starts were again attempted at lower than 20°F (-7°C) temperatures to stretch the limitations of the LDSI as an M100 cold start system. These attempts were again unsuccessful. It was decided to try another FTP in the CETC at a higher temperature, 30°F, in order to complete a successful test which would still represent a significant improvement in M100 cold startability. On this test, cranking time was almost 30 seconds, and driveability was again quite poor. However, the vehicle exhibited no power loss throughout the test and did not stall during idle periods. The exhaust temperatures rose sharply during Bag 2, and it was decided to stop the test because the rubber tailpipe boot which connects the vehicle to the CVS emission analyzer began to melt. Bag 1 was again analyzed and found to be much cleaner at 30°F (-1°C) than at 20°F (-7°C) with about one-half the CO and methanol emissions of the colder test. Gasoline equivalent fuel economy improved to 12.3 MPG in Bag 1 at 30°F.

VI. Discussion

The test results obtained here represent a significant improvement in lowering the minimum ambient temperature at which an M100-fueled vehicle can be cold started compared to otner methanol cold start programs previously and currently being performed by EPA. With long duration spark ignition used

as the only cold start system, M100 vehicle cold starts were obtained down to 20°F (-7°C) where previously these vehicles had difficulty being started at temperatures much below the flashpoint of methanol, 52°F (11°C). There did not appear to be any correlation between cranking time and ambient temperature, though the same starting procedure was employed upon each low ambient temperature cold start attempt.

The cold start emissions measured in Bag 1 of the FTP at 20°F and 30°F were quite high, particularly CO and methanol emissions. The vehicle obtained 10.6 MPG at 20°F and 12.3 MPG at 30°F over Bag 1 of the FTP on a gasoline-equivalent basis.

More extensive testing may be needed to determine why the vehicle had difficulty completing the FTP at low ambient temperatures.

The primary objective of the test program was the evaluate cold startability of the LDSI system at low temperatures, and this objective was accomplished. Optimization of warm-up emissions performance was not an objective of this test program since neither the LDSI system or any other control strategy was employed to limit exhaust emissions under these operating conditions. The warm-up (Bag 1) emissions are discussed here because they are an important indicator of cold start and cold transient combustion, and their measurement with M100 as the fuel is a result not previously accomplished by EPA.

Future testing could include evaluation of the LDSI system on other vehicles, emission testing in conjunction with a catalyst and/or alternate cold start fueling strategies. The ignition system could be tested in combination with other neat methanol cold start systems under development such as an ultrasonic fuel atomizer, direct injection, or a higher speed starter. Further optimization of the long duration spark ignition strategy itself, including alternate ignition timing strategy development, may help achieve reliable cold starts at ambient temperatures lower than previously accomplished.

VII. Acknowledgments

The author wishes to acknowledge the assistance of Hiroki Kawajiri of Nissan for supplying the LDSI system, Michael Murphy of SDSB for the development of the LDSI pulse interface circuit, James Garvey and Rodney Branham of TEB for performing the exhaust emission testing and analysis, and Jennifer Criss and Marilyn Alff of CTAB for word processing support and final report preparation.

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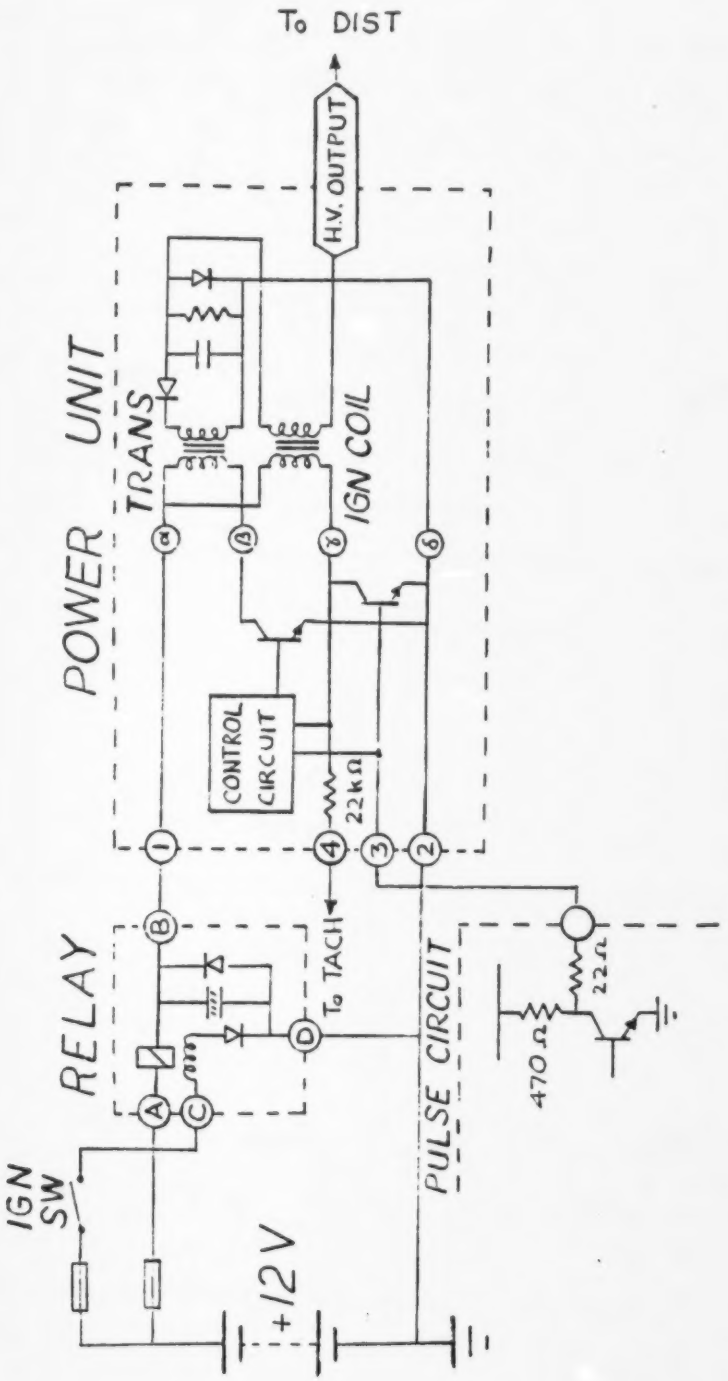
APPENDIX A



Project:	Date:	Drawn By:
LONG DURATION SPARK	5/31/89	ROBERT I. BRUETSCH

APPENDIX B

PX = 101.22 mS PY = 160.84 mV PN = 10122

QX = 112.81 mS QY = -32.227 mV QN = 11251

PQX = 11.590 mS PQY = -192.27 mV PQN = 1159

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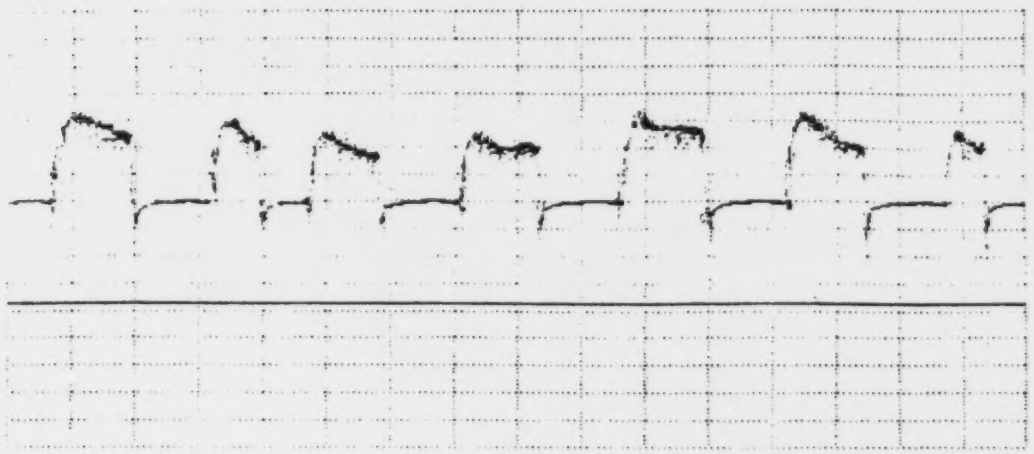
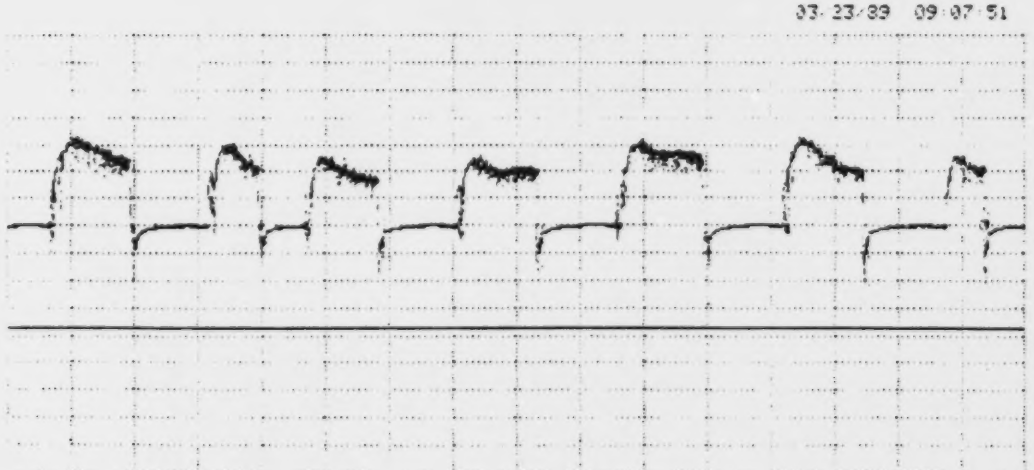


P[illegible] = [illegible] mS P = 170.30 mV PN = 10170

QX = 112.25 mS QY = -30.752 mV QN = 11225

PQX = 10.550 mS PQY = -200.96 mV PQN = 1055

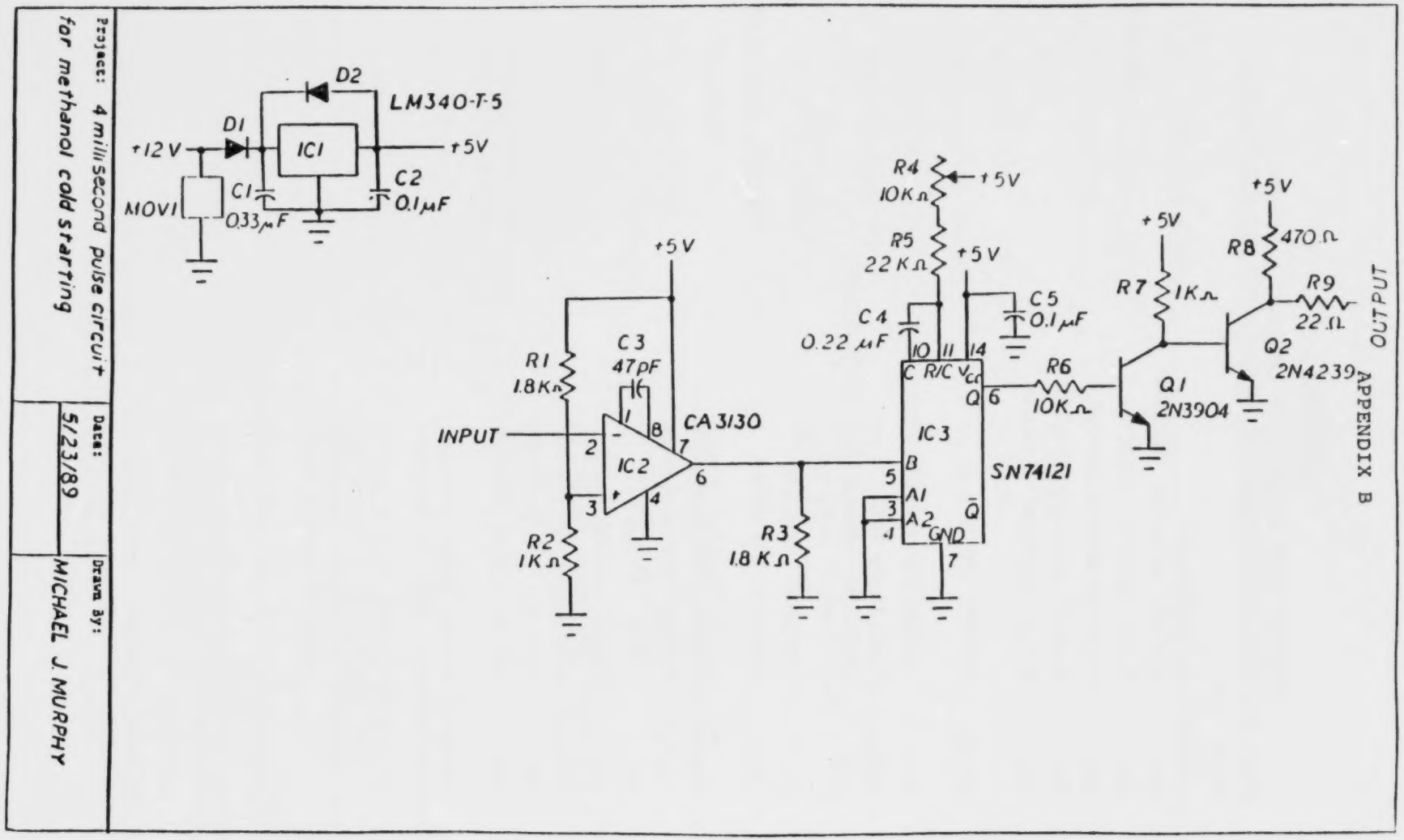
03/23/89 09:07:51



PX = 152.00 mS PY = 147.95 mV PN = 15263

QX = 157.24 mS QY = 5.3477 mV QN = 15724

PQ = 5.2400 mS PQY = -141.60 mV PQN = 461


D2
LM340-T-5
D1
+12 V
IC1
+5V
MOV1
C1
0.33μF
C2
0.1μF
+5V
R1
1.8KΩ
C3
47pF
INPUT
CA3130
IC2
R2
1KΩ
R3
1.8 KΩ
R4
10KΩ
+5V
R5
22 KΩ
+5V
C4
0.22 μF
C5
0.1μF
IC3
SN74121
R6
10KΩ
+5V
R7
1KΩ
R8
470Ω
R9
22Ω
Q1
2N3904
Q2
2N4239
OUTPUT
APPENDIX B
Project: 4 millisecond pulse circuit for methanol cold starting
Date: 5/23/89
Drawn By: MICHAEL J. MURPHY

APPENDIX B

Parts List

C1:	0.33µF polyester capacitor
C2:	0.1µF ceramic capacitor
C3:	47pF ceramic capacitor
C4:	0.22µF polyester capacitor
C5:	0.1µF polyester capacitor
D1,D2:	1N4003 diode
IC1:	LM340-T-5 voltage regulator
IC2:	CA3130 op amp
IC3:	SN74121 monostable multivibrator
Q1:	2N3904 transistor
Q2:	2N4239 transistor
R1, R3:	1.8kΩ 1/4 w resistor
R2,R7:	1.0kΩ 1/4 w resistor
R4:	10kΩ trimmer
R5:	22kΩ 1/4 w resistor
R6:	10kΩ 1/4 w resistor
R8:	470 Ω 1/4 w resistor
R9:	22 Ω 1/4 w resistor

APPENDIX C

METHANOL-POWERED VOLKSWAGEN TEST VEHICLE
SPECIFICATIONS AND CHANGES TO ACCOMMODATE METHANOL FUEL

Vehicle Item	Specification/Change
Engine:	
Displacement	1.61 liters
Bore	8.00 cm
Stroke	8.00 cm
Compression ratio	12.5:1
Valvetrain	Overhead camshaft
Basic engine	GTI basic engine - European high-performance engine to withstand higher loads - U.S. cylinder head
Main Fuel System:	
General	Bosch K-jetronic CIS fuel injection with Lambda feedback control; calibrated for methanol operation
Pump life	1 year due to corrosiveness of methanol; improved insulation on wiring exposed to fuel
Accumulator-maximum holding pressure	3.0 bar
Fuel filter	One-way check valve deleted because of fuel incompatibility
Fuel distributor	5.0-5.3 bar system pressure, calibration optimized for methanol, material changes for fuel compatibility
Air sensor	Modified air flow characteristics
Fuel injectors	Material changes for fuel compatibility; plastic screen replaced by metal screen
Cold-start injectors	2 injectors, valves pulse for 8 seconds beyond start mode below 16°C (60°F)

APPENDIX C (CONT'D)

METHANOL-POWERED VOLKSWAGEN TEST VEHICLE
SPECIFICATIONS AND CHANGES TO ACCOMMODATE METHANOL FUEL

Vehicle Item	Specification/Change
Fuel injection wiring	Modified to accommodate relays and thermo-switch
Idle setting	Specific to methanol calibration
PCV:	PCV valve with calibrated plunger no orifice
Ignition:	
Distributor	Slightly reduced maximum centrifugal advance and slightly modified vacuum advance/retard characteristics
Standard spark plugs	Bosch W4CC
Transmission:	
General	1981 production automatic 3-speed
Torque converter ratio	2.44
Stall speed	2000-2200 rpm
Gear ratios:	
1	2.55
2	1.45
3	1.00
Axle	3.57
Fuel Tank:	
Material	Steel
Coating	Phosphated steel
Seams and fittings	Brazed
Cap	European neck and locking cap
Fuel	Neat methanol (M100)

COMPOSITE TEST RESULTS FROM 2660S-MX13

TEST NUMBER 893480 METHANE MEASURED ? NO METHANOL MPG 5.28
M100.FUEL METHANOL MEASURED ? NO GASOLINE MPG 10.62
OTR TEST PROCEDURE "FACTOR" 2.0105

TEST NUMBER	BAGS	MILES	< CURRENT TEST RESULTS > HC	CO	CO2	NOX	CH4	< ----- PROPOSED TEST CALCULATIONS (GRAMS/MILE) ------ > NMHC	HC	CO	CO2	NOX	OMHCE	CH3OH	HCHO
893480	1	3.162	47.178	148.258	351.41	1.080	-9.999	-9.999	5.554	148.264	351.53	1.081	61.091	******	-0.00017

TEST NUMBER 893621 METHANE MEASURED ? NO METHANOL MPG 6.13
M100.FUEL METHANOL MEASURED ? NO GASOLINE MPG 12.32
OTR TEST PROCEDURE "FACTOR" 2.0105

TEST NUMBER	BAGS	MILES	< CURRENT TEST RESULTS > HC	CO	CO2	NOX	CH4	< ----- PROPOSED TEST CALCULATIONS (GRAMS/MILE) ------ > NMHC	HC	CO	CO2	NOX	OMHCE	CH3OH	HCHO
893621	1	3.295	32.076	72.000	426.11	1.931	-9.999	-9.999	3.774	72.005	426.27	1.931	41.511	87.144	-0.00018

APPENDIX D

BAG BY BAG TEST RESULTS FROM 2660S-MX13

TEST NUMBER 893480
M100.FUEL METHANE MEASURED ? NO
OTR TEST PROCEDURE METHANOL MEASURED ? NO

TEST NUMBER	BAG	MILES	< CURRENT TEST RESULTS > H C	C O	CO2	NOX	CH4	< ----- PROPOSED TEST CALCULATIONS (GRAMS/BAG) NMHC	H C	C O	CO2	NOX	OMHCE	CH3OH	HCHO
893480	1	3.162	149.176	468.792	1111.14	3.414	-9.999	-9.999	17.561	468.810	1111.54	3.419	******	405.521	-0.00052

TEST NUMBER 893621
M100.FUEL METHANE MEASURED ? NO
OTR TEST PROCEDURE METHANOL MEASURED ? NO

TEST NUMBER	BAG	MILES	< CURRENT TEST RESULTS > H C	C O	CO2	NOX	CH4	< ----- PROPOSED TEST CALCULATIONS (GRAMS/BAG) NMHC	H C	C O	CO2	NOX	OMHCE	CH3OH	HCHO
893621	1	3.295	105.689	237.241	1404.04	6.363	-9.999	-9.999	12.434	237.257	1404.56	6.363	******	287.140	-0.00059

APPENDIX D (CONT'D)

BAG BY BAG TEST RESULTS FROM 2660S-MX13

TEST NUMBER 893480
M100.FUEL METHANE MEASURED ? NO
OTR TEST PROCEDURE METHANOL MEASURED ? NO

TEST NUMBER	B A G	MILES	< CURRENT TEST RESULTS > H C	C O	CO2	NOX	<-------- PROPOSED TEST CALCULATIONS (GRAMS/MI) ----------> CH4	NMHC	H C	C O	CO2	NOX	OMHCE	CH3OH	HCHO
893480	1	3.162	47.178	148.258	351.41	1.080	-3.162	-3.162	5.554	148.264	351.53	1.081	61.091	128.248	-0.00017

TEST NUMBER 893621
M100.FUEL METHANE MEASURED ? NO
OTR TEST PROCEDURE METHANOL MEASURED ? NO

TEST NUMBER	B A G	MILES	< CURRENT TEST RESULTS > H C	C O	CO2	NOX	<-------- PROPOSED TEST CALCULATIONS (GRAMS/MI) ----------> CH4	NMHC	H C	C O	CO2	NOX	OMHCE	CH3OH	HCHO
893621	1	3.295	32.076	72.000	426.11	1.931	-3.035	-3.035	3.774	72.005	426.27	1.931	41.511	87.144	-0.00018

APPENDIX D (CONT'D)